Synopsis

Title of the proposed work :

Heatline analysis on natural convection of nanofluids in cavity flows

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Registration No. : **VB- 2096 of 2014-15, Date : 09.09.2014**

Keywords : Double-diffusive, Nanofluid, Heatline, Massline, Magnetic field, Aspect ratio of a cavity.

A nanofluid is a base fluid with suspended metallic nanoparticles[1]. As traditional fluids used for heat transfer applications such as water, mineral oils and ethylene glycol have a rather low thermal conductivity, nanofluids with relatively higher thermal conductivities have attracted enormous interest among researchers due to their potential in enhancement of heat transfer with little or no penalty in pressure drop. Eastman et al. [2] showed that an increase in thermal conductivity of approximately 60% can be obtained for a nanofluid consisting of water and 5 % volume of CuO nanoparticles. This is attributed to the increase in surface area due to the suspension of nanoparticles. Also, it was reported that a small amount (less than 1% volume fraction) of copper nanoparticles or carbon nanotubes dispersed in ethylene glycol or oil can increase their inherently poor thermal conductivity by 40% and 150%, respectively [3,4]. Das et al. [5] reported a 24-fold increase in thermal conductivity enhancement for water-based nanofluids containing Al_2O_3 or CuO nanoparticles over a small temperature range. Keblinski et al. [6] reported on the possible mechanisms of enhancing thermal conductivity, and suggested that the size effect, the clustering of nanoparticles and the surface adsorption could be the major reason of enhancement, while the Brownian motion of nanoparticles contributes much less than other factors since Brownian motion of nanoparticles is too slow to transport significant amount of heat through a nanofluid and this conclusion was also supported by their results of molecular dynamics simulation. Wang et al. [7] have studied experimentally the effective thermal conductivity of liquids with 25 nm SiO_2 particle inclusions and observed the percolation pattern of particle clustering by scanning tunnel microscopic (STM) photos. It was believed that clustering could affect the enhancement prominently. Wang et al. [8] have used a fractal model for predicting the effective thermal conductivity of liquid with suspension of nano-particles and found that it predicts well the trend for variation of the effective thermal conductivity with dilute suspension of nanoparticles. Several other models have been proposed for calculating the effective apparent thermal conductivity of a solid–fluid system [9–11].

The convective heat transfer characteristic of nanofluids depends on the thermo-physical properties of the base fluid and the ultra fine particles, the flow pattern and flow structure, the volume fraction of the suspended particles, the dimensions and the shape of these particles. The utility of a particular nanofluid for a heat transfer application can be established by suitably modeling the convective transport in the nanofluid [14]. Several studies of convective heat transfer in nanofluids have been reported in recent years. Khanafer et al. [15] investigated the problem of buoyancy driven heat transfer enhancement of nanofluids in a two-dimensional enclosure. A few earlier works [16–21] involve studies on free convection in rectangular enclosures with nanofluids and enhancement of heat transfer rate was found. A few investigations on natural convection within trapezoidal enclosures have been carried out by earlier researchers[12,13,22,23]. Lyican et al.[12] investigated the natural convective flow and heat transfer within a trapezoidal enclosure with parallel cylindrical top and bottom walls at different temperatures and plane adiabatic side walls. Karyakin[13] reported two-dimensional laminar natural convection in an isosceles trapezoidal cavity. The heat transfer rate is found to increase with the increase in base angle. Peric[22] studied natural convection in trapezoidal cavities using a control volume method and observed the convergence of results for grid-independent solutions. Kuyper and Hoogendoorn[23] investigated laminar natural convection flow in trapezoidal enclosures to study the influence of the inclination angle on the flow and also the dependence of the average Nusselt number on the Rayleigh number. Oztop and Abu-Nada [24] studied heat transfer and fluid flow due to buoyancy forces in a partially heated enclosure using nanofluids with various types of nanoparticles and found heat transfer enhancement at a low aspect ratio. Abu-Nada [25] reported on the application of nanofluids for heat transfer enhancement of separated flows encountered in a backward facing step. Further, the effects of variable viscosity and thermal conductivity of Al_2O_3– Water nanofluid on heat transfer enhancement in natural convection were studied [26]. Enhancement of heat transfer with nanofluids was also found to occur in various applications such as natural convection cooling of a localized heat source [27], natural convection in enclosures with various inclinations [28], periodic natural convection in a nanofluid-filled enclosure with oscillating heat flux [29], natural convection in enclosures with one side is sinusoidally heated or cooled [30], natural convection in an inclined enclosure with a heat source [31], experimental studies on natural convection in vertical square enclosures [32], natural convection within a cavity with two pairs of heat source-sink [33], etc. Nield and Kuznetsov [34] carried out analytical investigations on the effect of vertical throughflow on the onset of convection in a horizontal layer of porous medium saturated with nanofluid. Their study primarily focuses on the dependence of the critical Rayleigh number for the non-oscillatory and oscillatory modes of instability on the thermophoresis and Brownian motion parameters for the cases with and without throughflow. Arifin et al. [35] investigated a non-isobaric Marangoni boundary layer flow that can be formed along the interface of immiscible nanofluids in surface driven flows due to an imposed temperature gradient. They found dual solutions for specific parameters. Ghasemi et al. [36] investigated the natural convection in an enclosure that is filled with a water– Al_2O_3 nanofluid and is influenced by a magnetic field. Their results show that the heat transfer rate increases with Rayleigh number, but that decreases with an increase of the Hartmann number. Although significant amount of works were carried out for the role of nanofluid on enhancement of heat transfer, but the detailed visualization on heat transport is yet to appear in the literature. The studies on visualization of heat transfer is important and that may further add new insight to assess the role of nanofluid on

the local and overall heat transfer enhancements. In general, the visualization of heat transfer is carried out using heatlines. Till date, heatline based analysis on the evaluation of heat transfer enhancement for natural convection in nanofluids within enclosures is yet to appear in literature. Heatline concept was developed by earlier researchers [37] to visualize conductive as well as convective heat transport. Heatlines typically represent heat functions which are energy analog of stream functions in such a way that the former intrinsically satisfies the thermal energy equation for energy flows while the later plays the same role in mass continuity equation to explain fluid dynamics. Heatlines are mathematically represented by heat functions which are in turn related to Nusselt number based on proper dimensionless form.

The objective of our research is to analyze the flow and thermal characteristics of water and nanofluids (Cu–water, TiO_2–water and Alumina–water) confined within trapezoidal cavity with various heating patterns of walls. Numerical investigations on heating characteristics within trapezoidal cavities will be carried out based on coupled partial differential equations of momentum and energy which will be solved using finite difference method to obtain the numerical simulations in terms of stream functions, heat functions, massfunction and isotherms.The jump discontinuity in Dirichlet type of wall boundary conditions for temperature at the corner points will be tackled by implementation of exact boundary conditions at those singular points as mentioned earlier [38]. Comparison of results will be shown for base fluid (water) and nanofluids. Visualization of heat flows would be demonstrated for both of base fluid and water to justify enhancement of heat transfer for various nanofluids. Quantitative comparison of heat transfer rates will also be done based on local and average Nusselt numbers.

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